The Influence of Planets on the Formation of Sun-spots.

By Arthur Schuster, F.R.S.

(Received in abstract and read March 23,—Complete MS. received May 3, 1911.)

1. This investigation deals with the correlation between the position of sun-spots at their first appearance and the heliocentric longitude of the principal planets. The available data reach back as far as 1874 inclusive, and are to be found in the publications of the Royal Observatory, Greenwich.

If we neglect the angle between the sun's equator and the ecliptic, and add the heliocentric longitude of the earth to the longitude of a spot referred to the central meridian, we obtain the heliocentric longitude of the sun-spot measured from the first point of Aries; deducting now the heliocentric longitude of a planet, we obtain the longitude of the spot referred to the central meridian as seen from the planet. Excluding spots near the eastern limb, many of which have been formed on the invisible hemisphere and are brought into view by the sun's rotation, the first photograph on which a spot appears gives the position of its origin within about 13° of longitude, provided there are no gaps in the daily records. For the reason given, no account has been taken of any spot which is first seen within 30° longitude from the eastern limb. Measured on the projected disc, the excluded portion covers at the equator a width of 2 minutes of arc or about the eighth part of the solar radius. The total number of spots dealt with is 4271.

2. Any planetary influence that may exist probably depends on the distance of the planet from the sun, and possibly on its mass and size, and in whatever way we combine these factors they point to Jupiter, Venus, and Mercury as most likely to be effective. I shall therefore deal primarily with these planets.

The position of the spot at its first appearance as seen from the planet having been obtained in the manner described, the solar surface was divided by circles of longitude into 12 equal compartments, starting with that meridian circle which is directly opposed to the central meridian as seen from the planet. Fig. 1 represents a section of the sun by the ecliptic and its division into compartments when a planet A is under discussion. The compartments are supposed to revolve with the planet, and, except at conjunction, they are

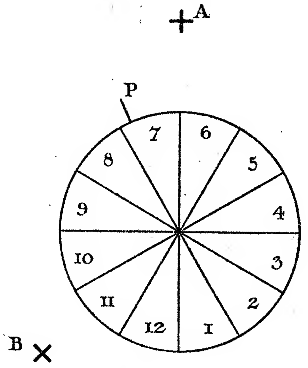

Fig. 1.

different for each planet, so that the spot at P formed in division 7, when the planet A is considered, would be entered as forming in division 3 in relation to a planet situated at B if its angular distance from B measured anti-clockwise is between 240° and 270°.

The whole available period of 36 years was divided into three groups. In the case of Jupiter and Mercury, each group included 12 years, but in the case of Venus the discussion was conducted on the basis of synodic revolutions instead of years, and the first group contains the spots which were observed during the eight synodic revolutions beginning with September, 1875, while the second and third groups each include the spots seen during the seven succeeding synodic revolutions.

3. Table I gives for each of the three planets and for each of the three groups the numbers of the spots first seen in the compartment indicated at the head of the columns. The last column gives the total number of spots in the group. Fig. 2 shows in diagrammatic form the number of spots which first appeared in each compartment during the whole period of 36 years. The curves are given separately for each planet and a fourth curve is added showing the average result for the three planets combined. In fig. 2 the curves are drawn taking account of the last group of years only. In the tables the heavier lines indicate divisions of the sun according to the quadrants, the centre line representing the central meridian. In the figures, short lines indicate the compartments, while the vertical lines passing through the figures indicate divisions according to quadrants, the central line representing the central meridian. On the vertical scale the distance between two horizontal lines drawn at the margin is 20 spots in fig. 2, and 10 spots in figs. 3, 4, and 5.

The remarkable difference, first pointed out by Mrs. Maunder, in the number of spots which make their first appearance respectively in the eastern and western half of the solar disc, made it advisable to separate the spots according to their position on the solar disc.

In Table II the whole period of 36 years is combined, but the spots are divided into three groups according to their position at first appearance. Group A includes all spots which are first seen between 60° and 30° east of the central meridian, while B refers to longitudes east between 30° of the central meridian, and C to all spots seen west of the central meridian. Fig. 4 gives in diagrammatic form the frequencies of first appearance of those spots west of the central meridian, while fig. 5 refers to those which first appear east of the central meridian, and which during their rotation round the sun's axis have not yet therefore passed it.

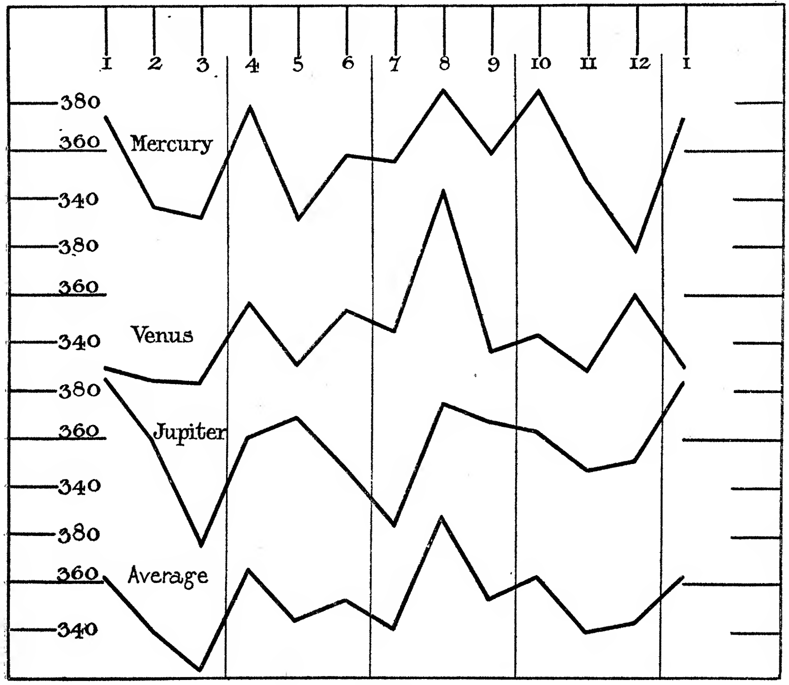
1
2
3
4
5
6
7
8
9
10
11
12
1
380
360
340
380
360
340
380
360
340
380
360
340
Mercury
Venus
Jupiter
Average

Fig. 2.

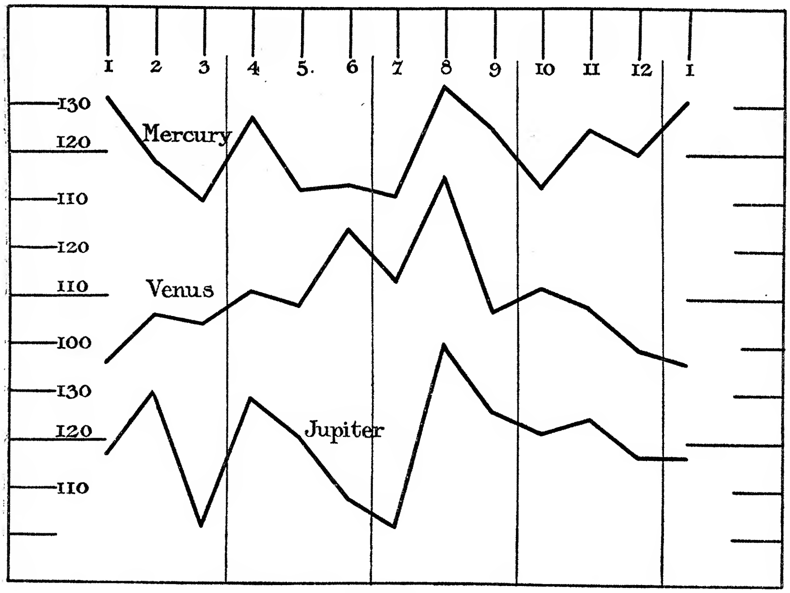
1
2
3
4
5
6
7
8
9
10
11
12
1
130
120
110
120
110
100
130
120
110
Mercury
Venus
Jupiter

Fig. 3.

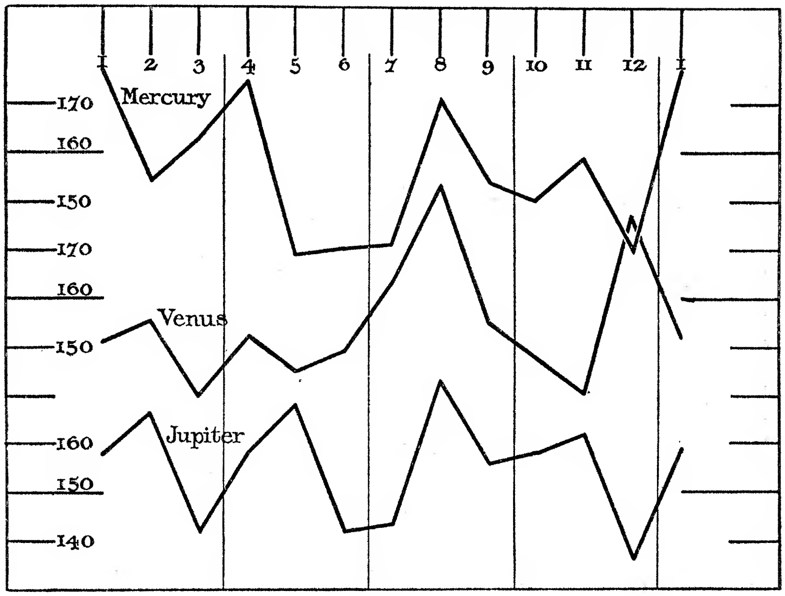
1
2
3
4
5
6
7
8
9
10
11
12
1
Mercury
170
160
150
Venus
170
160
150
Jupiter
160
150
140

Fig. 4.

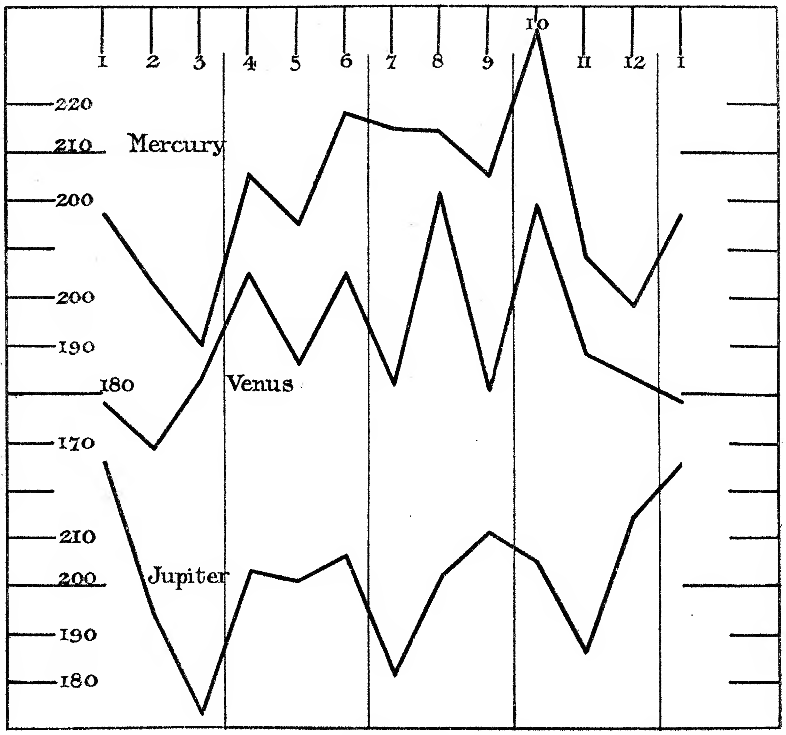
1
2
3
4
5
6
7
8
9
10
11
12
1
Mercury
220
210
200
Venus
200
190
180
170
Jupiter
210
200
190
180

Fig. 5.

Table I.

Planet.	Group.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	Sum.
Mercury	I...........	99	97	88	104	84	89	92	96	85	106	84	71	1095
	II...........	144	122	135	148	138	156	153	155	149	166	138	127	1731
	III...........	131	118	110	127	112	113	111	134	125	113	125	120	1439
Δ = 18·0	Sum......	374	337	333	379	334	358	356	385	359	385	347	318	4265
Venus	I...........	98	94	88	103	95	91	97	111	96	99	81	111	1164
	II...........	135	124	131	143	128	139	135	158	133	132	139	150	1647
	III...........	96	106	104	111	108	124	113	135	107	112	108	99	1323
Δ = 16·2	Sum......	329	324	323	357	331	354	345	404	336	343	328	360	4134
Jupiter	I...........	90	86	86	78	89	93	87	96	104	97	93	96	1095
	II...........	178	144	127	154	159	147	135	139	137	144	129	138	1731
	III...........	117	130	102	129	121	108	102	140	126	122	125	117	1439
Δ = 15·3	Sum......	385	360	315	361	369	348	324	375	367	363	347	351	4265
Average for three planets	...	362	340	323	365	344	353	341	388	354	363	340	343	4221

Table II.

Planet.	Longitude.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	Sum.
Mercury	A, −60°, −30°	111	88	83	112	98	112	103	117	105	127	104	78	1238
	B, 0° to −30°	86	95	87	93	97	106	112	97	100	108	84	100	1165
	C, 0° to +90°	177	154	163	174	139	140	141	171	154	150	159	140	1862
Venus	A, −60°, −30°	79	83	97	104	92	99	109	109	85	108	91	102	1158
	B, 0° to −30°	99	86	86	101	94	106	73	112	96	110	97	81	1141
	C, 0° to +90°	151	155	140	152	145	149	163	183	155	125	140	177	1835
Jupiter	A, −60°, −30°	112	102	109	111	82	105	95	101	112	102	98	109	1238
	B, 0° to −30°	114	92	64	92	119	101	86	101	99	103	88	106	1165
	C, 0° to +90°	159	166	142	158	168	142	143	173	156	158	161	136	1862

For the purpose of comparison it appeared to be desirable to test also some planet from which no effect was to be expected. Mars and Saturn were chosen for the purpose, and the results are given in Table III. Saturn was treated, however, in a somewhat simplified manner, its heliocentric position being considered constant during each year, and suddenly altered at the end of it. It may be mentioned incidentally that this investigation originated in the desire to find a possible regularity in the birthplace of spots looked at from a fixed point in space. While laying the discussion of this part of the subject aside for the present, I include in the table the statistics resulting from considering an imaginary planet fixed in space at the first point in Aries; the name of this constellation is attached to the number referring to this imaginary planet.

Table III.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	Δ.
Mars......	337	330	360	352	391	361	374	364	361	326	357	352	13·3
Saturn ...	323	363	330	359	381	396	357	371	372	338	330	341	18·9
Aries......	375	339	394	357	332	373	351	362	367	307	340	364	17·6

4. I may now briefly discuss the conclusions to be drawn from the tables and figures. I must insist at once, that the variability of the numbers given in the different compartments is not by itself sufficient to indicate any planetary effect. Even though the formation of sun-spots were quite independent of the position of the planets, we should still have differences in the compartments, and the laws of probability lead us to expect that these differences would not be very much smaller than those actually exhibited in the tables. The argument for the real existence of a planetary effect rests entirely on the similarity in the apparent effect of the three important planets. An inspection of fig. 2 shows that in the formation of spots, the compartment 3 has a minimum in all three cases. An observer stationed in that compartment on the sun would have the planet just below his eastern horizon and about to rise. If the complete rotation of the sun be divided into 24 hours, the imaginary observer would find an increased effect within the first two hours after the planet has arisen. This is followed by a diminution in the activity, finally rising again to a decided maximum about three hours after the planetary noon (compartment 8). Without looking into details, in which we must expect irregularities, I think that agreement in the general features of the curves for Mercury and

Venus (fig. 2) is remarkable. The only discrepancy occurs in compartment 12, or probably, rather, in compartment 1, which in the case of Venus is unduly depressed. Though Jupiter is not quite as concordant, the minimum in compartment 3 is well marked, and the maximum in 8 unmistakable. Fig. 3 shows that the principal features of the curves are found in the observations made during the last 12 years only. Figs. 4 and 5 are somewhat puzzling; they seem to show that the regularities exhibited by the spots as a whole are mainly due to those spots, which make their first appearance on the western half of the sun's disc. Though some similarity may be traced in the curves of Venus and Mercury in the spots first appearing in the eastern portion, the type of the regularity seems to be changed except for the minimum at or near 3, which persists. This matter will be further referred to in § 6, but one peculiarity may here be noted: a maximum in compartment 10, which for the combined spots (fig. 1) is pronounced only in the case of Mercury (accidentally or otherwise), is here found also with Venus, and to be due to those spots which first appear east of the central meridian. There seems, indeed, to be a tendency of this maximum to replace the one in compartment 8.

The observations are not sufficiently extended to give any information as to the differences in magnitude or kind which may exist between the effects of different planets. Mercury and Jupiter seem to indicate an increased activity on that side of the sun which is turned away from a planet, while Venus does *not* show this increase. Further observations are needed before we can decide whether the difference is real.

5. The question naturally presents itself whether two planets, acting in conjunction, have an influence which is greater than the one to be expected by mere superposition. I have therefore collected all cases in which the compartment of first appearance had the same numerical value for any two of the planets Mercury, Venus, and Jupiter, or for the three combined. The result is given in Table IV, and is not very conclusive.

Table IV.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	Sum.
Mercury and Venus ……	33	22	21	32	21	20	32	35	27	34	34	23	334
Mercury and Jupiter……	16	20	16	30	19	26	25	23	21	25	20	23	264
Venus and Jupiter………	23	25	22	26	34	27	26	30	34	40	25	29	341
Sum …………	72	67	59	88	74	73	83	88	82	99	79	75	939

But though the number of spots dealt with is much reduced, the distribution in the different compartments is very similar. The minimum still appears decidedly in compartment 3 and the maximum remains in compartment 8 for the combination Mercury-Venus; for the summed effect of the three planets the maximum is shifted to compartment 10. The much greater number of spots appearing at conjunction when Venus is one of the planets concerned is probably significant. The distribution into compartments of twenty-five spots formed at the simultaneous conjunction of the three planets is given in Table V.

Table V.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	Sum.
Mercury, Venus, and Jupiter	0	1	4	7	1	3	1	1	0	3	2	2	25

The numbers are too few to allow any importance to be attached to the figures, because differences in the exposed hemisphere of the sun, according to the position of the earth at the time of conjunction, are insufficiently eliminated.

6. Is there any significance in these results, and may we be reasonably certain that the regularities of the past records will be repeated in the future? An application of the theory of probabilities to natural phenomena always presents the difficulty that it must compare what actually happens with what would happen on the supposition of a purely accidental incidence of events. But nothing is accidental in nature; and probably no two events are absolutely disconnected. We are forced to reason, as if the absence of any correlation between two sets of events distributes one set *relatively to the other* as if its occurrence were regulated by chance only. On this supposition we may calculate the probability that our results establish a real correlation between planets and sun-spots. Imagine the sun to be divided into 12 compartments by equidistant meridian circles; the probability (p) that any spot is first observed in any one definite compartment is 1/12, and the probability that out of N spots n shall appear in that compartment is, writing $q = 1-p$ and $m = \mathrm{N}-n$,

$$\frac{\mathrm{N}}{n\,!\,m\,!}p^n q^m.$$

The average value of n is $p\mathrm{N}$.

If the number N be large, Stirling's theorem gives for the probability that the number in any compartment lies between $p\mathrm{N}-r$ and $p\mathrm{N}+r$ the expression*

$$\frac{2}{\sqrt{\pi}}\left[\int_0^w e^{-w^2}du+\frac{w}{2r}\,e^{-w^2}\right], \quad \text{where} \quad w = r/(2\mathrm{N}pq)^{\frac{1}{2}}.$$

In the case to be considered, the last term is small compared with the first, and its effect would be to increase the probability of a real correlation; it may therefore be neglected. Introducing the numerical factor and assuming provisionally that the probability of the number of spots being greater than $p\mathrm{N}+r$ is the same as that of its being smaller than $p\mathrm{N}-r$, I find the probability that the actually observed excesses in the compartment 8 are due to chance only, is 0·05, 0·00041, 0·138 for the planets Mercury, Venus, and Jupiter respectively. If we take each planet separately, we have to consider that there are 12 compartments, and in order to obtain the probability of a given excess occurring in some one compartment, we should have to multiply the above figures by 12. It is seen that only in the case of Venus do the numbers help to establish a real connection. But when we come to combine the results, and calculate the probability that the excesses should all occur in the same compartment, the verdict seems decisive. This probability, obtained by taking 12 times the product of the three figures, is $3{\cdot}4\times10^{-5}$. I find, similarly, for the probability of the deficiency in compartment 3, the value $1{\cdot}71\times10^{-3}$, and the probability that both effects should appear together is only $5{\cdot}8\times10^{-8}$, or 1 in 17 million.

The results of the above calculation might be seriously altered, if a number of groups of spots frequently occur simultaneously along the same meridian. It is found, indeed, that frequently a spot in the northern latitude is accompanied by a spot in the southern latitude in nearly the same longitude. Such a connection may be quite disconnected from any planetary action, but would tend to make the deviation from the mean in different compartments greater than what is expected from the theory of probability. To test to what extent this is the case, I have computed the mean deviation of the number of spots observed in each compartment from its average. The figures are given in Tables I and III, under the designation Δ. The mean value of Δ for the planets Mercury, Venus, and Jupiter is 17, and this is very little larger than the number found for the mean deviation, when the spots are examined with reference to Mars, Saturn, or a point fixed in space. The mean deviation, calculated on the supposition of an accidental distribution, is 14·4. If we treat the higher value actually found as due to the occurrence of spots in groups, and correct the previous calculation accordingly, the probability that we are being misled by an accidental coincidence becomes somewhat greater, and becomes about 2·5 parts in a million. This means that if there were 400,000 worlds like ours there would on an average be one, and only one, in which the distribution of spots would accidentally indicate a planetary effect such as the one described. We cannot go further than this for the present.

---

* Todhunter, 'History of Probability,' p. 551.

7. In a paper already alluded to, Mrs. Maunder* gave an exhaustive and important discussion of an apparent effect of the earth on the formation and growth of sun-spots. In the light of the present investigation we must conclude that, unless the earth acts very much more strongly than the other planets, the effect found by Mrs. Maunder is not a true planetary effect, but depends on the point of view from which a spot is looked at from the earth. I am here only concerned with the first formation, or, as Mrs. Maunder appropriately calls it, the birthplace of sun-spots, and Table VI shows how marked and regular is the preponderance of the number of spots born in the eastern half of the solar disc. The numbers are given in percentages of the total number observed during the three successive periods of 12 years, but the figures in the first column have little significance, because they include all spots born on the invisible hemisphere and brought into view by the rotation of the sun.

Table VI.

Period.	4.	5.	6.	7.	8.	9.	Number of spots.
1874—1885......	41	18	15	13	10	3	1869
1885—1896......	40	17	16	14	9	2	2909
1897—1909......	38	18	17	14	10	3	2341
Average......	40·0	17·8	16·0	13·7	9·8	2·7	7119

At first sight it would seem that a preponderance of one side of the sun over the other must be due to some want of symmetry in the conditions of visibility; but this is not the case. On the contrary, the preponderance of the eastern half mainly points to an increased facility of detecting a sun-spot when it is near the centre of the solar disc. It is possible to imagine a symmetrical law of visibility which would give a uniform distribution of new spots on one side of the disc and a total absence on the other.

---

* 'Monthly Notices R.A.S.,' 1907, vol. 67, p. 451.

Although not altogether germane to the main purpose of this paper, a discussion of the effects of different conditions of visibility, which is not quite obvious and has never been taken into consideration, may be useful to others. A sun-spot, before it appears as such, probably exists in some preliminary stage in which it shows itself on the spectro-heliograms, but not on ordinary photographs of the sun. Imagine a spot in its invisible stage to grow at an average rate k per unit time, so that its area becomes kt at time t, and assume that it must reach a certain size s before it becomes visible. (Possibly s includes other conditions besides size.) A spot, according to this view, appears to us first, when it has been in existence during a time s/k. If it shows itself first in longitude λ, but has really been formed in longitude λ_1, the difference $\lambda - \lambda_1$ is equal to $\omega s/k$, where ω is the angular velocity at the sun's surface.

If the visibility of a spot depends on our point of view, s will be a function of the longitude of the spot where it first appears to us, and we may therefore write

$$\lambda_1 = \lambda - f(\lambda), \qquad d\lambda_1 = d\lambda\,[1 - f'(\lambda)].$$

If N_1 represents the number of spots generated in unit time in unit range of longitude, and $N d\lambda$ the number of those which are first observed in the range $d\lambda$, we have

$$N d\lambda = N_1 d\lambda_1 = N_1 d\lambda\,[1 - f'(\lambda)],$$

and hence

$$N = N_1 [1 - f'(\lambda)].$$

We shall assume N_1 to be constant, and $f(\lambda)$ to have the same value for equal positive and negative longitudes. It follows that $f'(\lambda)$ will be numerically equal and have opposite signs for corresponding points in the two halves of the solar disc. For the same distance from the centre we have therefore

$$\begin{aligned} N_+ &= N_1 [1 - f'(\lambda)], \\ N_- &= N_1 (1 + f'(\lambda)], \\ N_- - N_+ &= 2N_1. \end{aligned}$$

If the centre of the disc favours the visibility, $f(\lambda)$ will be smallest when $\lambda = 0$, and $f'(\lambda)$ will be positive on the positive side, hence there will be an excess of spots which first appear to form on the negative side, which is the eastern half of the sun's disc. This excess, therefore, only proves an increased condition of visibility near the centre, but, in itself, no want of symmetry. If, as an example, we assume $f(\lambda)$ to be equal to $a + \lambda$ for the positive values of λ, and $a - \lambda$ for the negative values of λ, it would follow that the formation of spots takes place at a uniform rate of

2N in the eastern half of the disc, but that no spot at all would be seen to form in the western half. The condition which must be satisfied, if the law of visibility is symmetrical with respect to the sun's centre, is $N_+ + N_- = 2N$. The sum in the birth rate of spots for equal positive and negative longitudes must therefore be constant in this case. Only in so far as the actual numbers do not show this constancy, but some excess for the smaller longitudes, is there any evidence for a want of symmetry in the conditions of visibility on the sun, or possibly for a change in N_1, which has been assumed to be constant.

This investigation was begun under the impression that the breaking out of spots afforded a convenient and simple test of planetary activity. The result has shown that, though convenient, it is beset by difficulties of interpretation which counterbalance the advantages of simplicity. The nature of the effect must therefore be left to future discussion.

8. Attempts to connect planets with solar activity have been made previously, and insufficient attention, perhaps, has been paid to a remarkable investigation by Warren de la Rue, Balfour Stewart, and Benjamin Loewy.* This may be due to the fact, which it would be wrong now to conceal, that Mr. Loewy, to whom, in a later series of investigations, and probably in this, the numerical work was entrusted, subsequently admitted that he had not dealt candidly with the figures. At what period he began not to do so, and whether the investigation here referred to is one of those affected, is not certain, but from my personal recollection of the history of these transactions I am inclined to believe that it is free from intentional errors. With all due reserve, we may therefore recall the important results of the investigation, which seem to have lapsed altogether into oblivion. Taking the long-lived groups of spots and treating their areas, the authors find, as Mrs. Maunder did subsequently, that the areas of the spots increase on the average as they cross the solar disc until they cross the central meridian, when they begin to decrease. But they also find, in direct opposition to Mrs. Maunder, that for equal longitudes east and west the areas are greater on the western side. The cause of this discrepancy must be left to be decided by further investigation. It is conceivably due to a systematic difference in the areas as measured from photographs or directly by eye estimate, as was done in the earlier records, or there may be some long-period change in the effect. After applying what is called an "earth correction," the authors find a very marked planetary effect, the areas being diminished at those parts of the sun which are turned towards the planet and increased at those parts which are turned away from the planet. Mercury and Venus give identical results, but none was found in the case of Jupiter. Though the

---

* 'Roy. Soc. Proc.,' 1872, p. 210.

numerical work is considerable, it is highly desirable that the correctness of these results should be tested with the better material which is now at our disposal.

9. A few words may be said on the *a priori* difficulties which may be felt in accepting a direct influence of a planet on solar phenomena. The tidal effect of planets on the sun's outer shell, which has been suggested by several writers, is generally believed to be too small to be effective, but gravitational effects may be much increased if there is a layer surrounding the sun in which gravitation is to some extent counterbalanced by radiation pressure. Arrhenius, in the theories he advocates, assumes such a cloudy layer, which is kept in suspension by radiation. It is easy to calculate the residual gravitation which must remain, so that the particles may not part company with the sun, in which case they must behave like satellites circulating round the sun in his time of revolution. If r be the radius of the sun ($6{\cdot}97 \times 10^{10}$ cm.) and v the velocity which a point of the sun's equator possesses in virtue of the sun's rotation round his axis (2·03 kilom. per second), the acceleration of a particle revolving with the sun, is $v^2/r = 0{\cdot}59$. By a numerical coincidence this is also the mean acceleration of the earth in its orbit round the sun.

It follows that the residual gravitational action of the sun on its suspended clouds is to the gravitational force of the earth on these clouds, as the mass of the sun is to the mass of the earth, or 330,000 times as great. That the earth's gravitational attraction, small though it may appear to be at first sight, may yet be effective in its action, is shown by comparing it with the action of the moon on a body placed on the surface of the earth, which only amounts to the 288,000th part of the weight of the body. But when we compare the effect of the earth on the sun with that of the moon on the tide, the advantage is considerably in favour of the former, because it is not, like the tidal action, differential in its nature, having the same direction on both sides of the sun.

We are not, however, dependent on radiation pressure for a plausible explanation of a planetary action on the outer shell of the solar globe, which may be purely electrostatic. The expulsion of negative electrons from hot bodies must leave the solar clouds positively electrified. On the other hand, negative particles ejected from the sun must to some extent accumulate in the outer layer of planetary atmospheres. An estimate of the maximum electrostatic effect of the planets on the solar atmosphere is easily made, because the electrification of the planetary atmosphere cannot exceed a certain value without dissipation into space. If σ be the charge per unit surface of the atmosphere, the outward force on each electron carrying a quantity of electricity e will be $4\pi\sigma e c^2$, where c is the velocity of light. This cannot be greater than the weight mg of this particle, where m denotes the mass of the ion to which the charge is attached.

The whole charge (E) of a planet having a radius a is $4\pi\sigma a^2$, so that this maximum charge is determined by $\mathrm{E}ec^2 = mga^2$. The electrostatic action of E on a charge e' at the surface of the sun, is $\mathrm{E}e'c^2/d^2$, if d be the distance between the two bodies and the gravitational attraction of the planet on a particle of mass m' is $m'ga^2/d^2$. We therefore reach the conclusion, that if the particles of the solar clouds have the same ratio e'/m' as charged particles in a planetary atmosphere, the electrostatic effect of the planet is equal to its gravitational effect. It need hardly be pointed out that the charge of the outer layer of its atmosphere produces no effect at the surface of a planet unless the uniformity of its distribution is temporarily disturbed. The electrification may therefore be responsible for some variation, periodic or otherwise, but not for any average effects taken over long periods of time.

The action of planets on particles ejected from the sun or returning to it may affect in other ways a delicately adjusted balance such as that which seems both electrically and gravitationally to regulate the phenomena at the solar surface, but enough has been said to show that a plausible explanation of a planetary action on sun-spots may be found without going beyond well-established processes.

Table VII, which explains itself, may assist in forming an estimate of the relative importance of different planets in their action on the sun. If the result depends on the number of electrons ejected by the sun and caught by the planet, we might expect the effect to diminish rapidly with distance. But if Jupiter exerts an influence comparable with that of Mercury the law of

Table VII.

Planets.	a.	m.	km/a^2.	$k'm/a^3$.	s.
Mercury	0·387	$2{\cdot}0 \times 10^{-7}$	0·43	1·10	6·6
Venus	0·723	$2{\cdot}5 \times 10^{-6}$	1·53	2·11	16·9
Earth	1·0	$3{\cdot}1 \times 10^{-6}$	1·0	1·0	17·6
Mars	1·52	$3{\cdot}2 \times 10^{-7}$	0·04	0·03	9·4
Jupiter	5·20	$9{\cdot}52 \times 10^{-4}$	11·27	2·17	37·0
Saturn	9·54	$2{\cdot}86 \times 10^{-4}$	1·00	0·11	18·0
Uranus	19·2	$4{\cdot}42 \times 10^{-5}$	0·38	0·02	3·5

a = relative distance from sun.

m = mass of planet referred to sun.

k and k' are constants adjusted so that the effect for the earth is unity.

s = angular diameter of planet, measured in seconds of arc, as seen at its mean distance from sun.

action can hardly diminish more rapidly than according to the inverse third power. If Jupiter has an effect, mass or size must come into play. I have added the last column to show the relative position of the planets with regard to their size and distance, irrespective of mass.

The Production of Characteristic Röntgen Radiations.

By R. Whiddington, B.A., St. John's College, Cambridge.

(Communicated by Sir J. J. Thomson, F.R.S. Received April 29,—Read May 25, 1911.)

We know from the researches of Barkla and Sadler and others that many of the phenomena in connection with the emission of secondary Röntgen rays can be explained quite simply by supposing that there are two distinct ways in which matter subjected to the action of primary rays may itself become a centre of radiation :—

(1) The primary rays may be scattered—an effect which is always very small.

(2) The primary rays may be transformed into a type of radiation characteristic of the transforming material and re-emitted as such.

This latter type of secondary radiation has been variously termed "characteristic," "homogeneous," "fluorescent." Each of these terms is expressive, but the first is perhaps the best, and will be used below.

The more important points in connection with the production and properties of this type of radiation are as follows :—

(1) A characteristic radiation is homogeneous or nearly so.

(2) It is only when the primary rays contain a constituent more penetrating than the characteristic to be excited that the stimulation can be effected (whence the term "fluorescent").

(3) The penetrating power of a characteristic radiation increases with the atomic weight of the emitting element.

(4) The characteristic radiation is invariably accompanied by emission of corpuscles from the surface of the radiator.

The experiments to be described have to do with (2) and (3), and define the quality of the softest primary radiation which can stimulate a characteristic, in terms of the velocity of the cathode rays within the exciting X-ray tube. The experiments consist broadly in directing a stream of cathode